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# **Evaluation and Characterization of Electro-Optic Components**

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14. ABSTRACT  Mach-Zehnder modulators and optical switches are essential components in photonics links. This report provides an understanding of how external variables such as optical power, RF power, wavelength, and temperature independently affect the performance of these devices. For applications involving wide-temperature fluctuations, EO Space modulator AX-0K1-20-PFU-SFU-S will provide superior performance. However, for multiple wavelength applications, this advantage is mitigated by a quadrature bias drift of 0.35 volts per 10 nm. While modulator AZ-1x2-0K1-12-PFU-PFU functions independent of wavelength, the adverse temperature dependence is severe. In comparing the SW-1x2-SO-PFU-PFU and SW-1x2-PI-SFU-SFU optical switches, the pm-fiber switch provided an additional 10 dB of cross-talk suppression. Furthermore, the pm-fiber switch has a smaller differential switching voltage required to optimize the power back and forth between output channels.					
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# Evaluation and Characterization of Electro-Optic Components

## 1. Executive Summary

Mach-Zehnder modulators and optical switches are essential components in photonics links. These devices often encounter real world variables that are not always present during laboratory testing. Accordingly, the primary objective of this research was to provide an understanding of how external variables such as optical power, RF power, wavelength, and temperature independently affect the performance of the devices. The significant variables and the affects on their respective component are as follows.

Switches:

EO Space switch (SW-1x2-SO-PFU-PFU):

- Optical power vs. voltage curve shifts with temperature
- $\Delta V_{\text{switch}} = 4.3$  volts
- Output 1 influenced at low temperatures
- Does not meet cross-over spec at high optical powers

EO Space switch (SW-1x2-PI-SFU-SFU):

- Optical power vs. voltage curve shifts with temperature
- $\Delta V_{\text{switch}} = 13$  volts

Modulators:

EO Space modulator (AX-0K1-20-PFU-SFU-S):

- Power levels and bias voltage stable over wide temperature range
- Bias voltage influenced by wavelength (0.35 V / 10 nm)
- S21 stable (~ 2.5 dB fluctuation over 60 °C)

EO Space modulator (AZ-1X2-0K1-12-PFU-PFU):

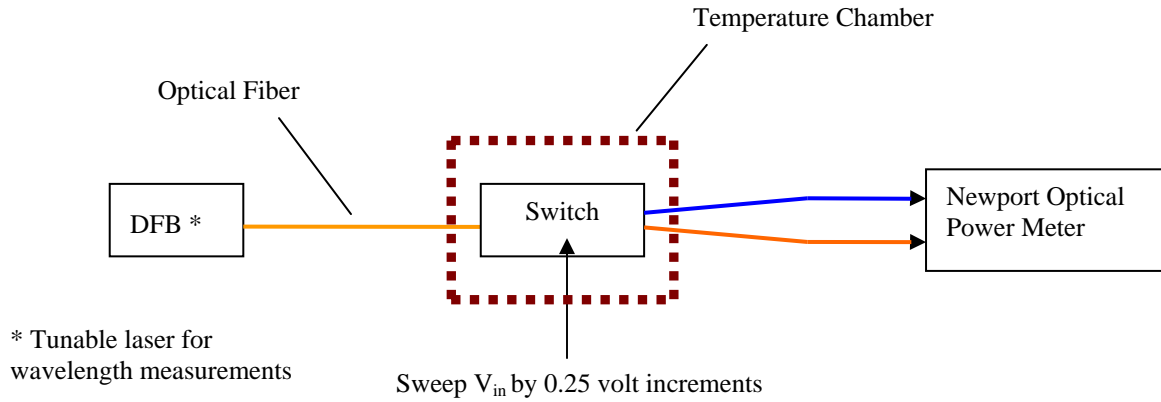
- Power levels and bias voltage significantly influenced by temperature
- Transfer function stable over wide range of wavelengths
- S21 unstable over temperature range (20 dB fluctuations)

## 2. Introduction

The purpose of this research was to characterize and compare various modulators and switches from EO Space Inc., 8711 148<sup>th</sup> Avenue NE, Redmond, WA 98052. The primary focus was to provide an understanding of how external variables such as optical power, RF power, wavelength, and temperature affect the performance of the devices.

## 3. Experimental Procedure - Switches

The first experiment involved the comparison of two optical switches (SW-1x2-SO-PFU-PFU and SW-1x2-PI-SFU-SFU). The part numbers show the first switch contained PM fiber for the input and output while the second switch used SM fiber for both. Fig. 1 shows the setup in which the two outputs of each switch were put directly into a Newport power meter to measure the optical responses while sweeping the applied input voltage.



*Fig. 1. Block diagram for measurement of optical switch response.*

## 4. Experimental Results - Switches

The following pages show the optical power, wavelength, and temperature dependence comparisons with the graph for the SM switch on top and the PM switch on the bottom. The SM switch displays the properties and optical response of a typical interferometer type switch while the PM switch response appears to behave like a mix of an interferometer and digital optical switch.

A major distinction is the difference in  $\Delta V$  of the two switches ( $\Delta V_{sm} = 12.8$  volts while  $\Delta V_{pm} = 4.25$  volts) where  $\Delta V$  denotes the differential voltage required to optimize the power back and forth between output channels. A physical representation of  $\Delta V$  for both switches is displayed in figures 2a and 2b.

As shown in fig. 2(a), the SM switch has negligible dependence on the optical input power. However, when the optical input power was increased from 10 mW to 40 mW

the PM switch no longer met the specification for cross-over – see fig. 2(b). Furthermore, the SM switch has less cross-over power in output channel two at the positive voltage null (-26 dB) versus the negative voltage null (-21.5 dB).

The wavelength dependence of each switch is shown in fig. 3 with the wavelength varied from 1530 – 1570 nm. The SM switch was stable with the exception of the null for output channel two shifting by 1.5 volts over the wavelength range. This effect would cause the cross-over power of that channel to change from -26 to -23 dB over the 1530 to 1550 nm wavelength range. As seen in fig. 3(b),  $\Delta V$  for the PM switch is stable for the wavelengths tested. However, this advantage is offset by the fact that the cross-over power is significantly worse, varying from -34 to -22 dB for the channel one output.

With respect to temperature (fig. 4), the response of both switches drifts by more than 2 volts over 0 to 60 degrees Celsius. Additionally, output 1 of the PM switch was adversely affected at low temperatures (measurement was repeated and verified). The PM switch performed well around room temperature. Unfortunately, as the temperature diverged away from 20 ° C in either direction the response curves were adversely affected.

#### **SW-1x2-PI-SFU-SFU**

$$\Delta V_{sm \text{ switch}} = 12.8 \text{ V } \{\text{spec} = \sim 13 \text{ V}\}$$

INPUT 1	<u>OUT 1 Loss</u>	<u>OUT 2 Loss</u>	INPUT 2	<u>OUT 1 Loss</u>	<u>OUT 2 Loss</u>
Thru	-2.8 dB {-2.9}	-24 dB {< -20}	Thru	-2.8 dB {-2.9}	-24 dB {< -20}
Cross-Over	-21.5 dB for -12.6 V -26.0 dB for 12.8 V {< -20}	-2.9 dB {-3.1}	Cross-Over	-21.5 dB for -12.6 V -26.0 dB for 12.8 V {< -20}	-2.9 dB {-3.1}

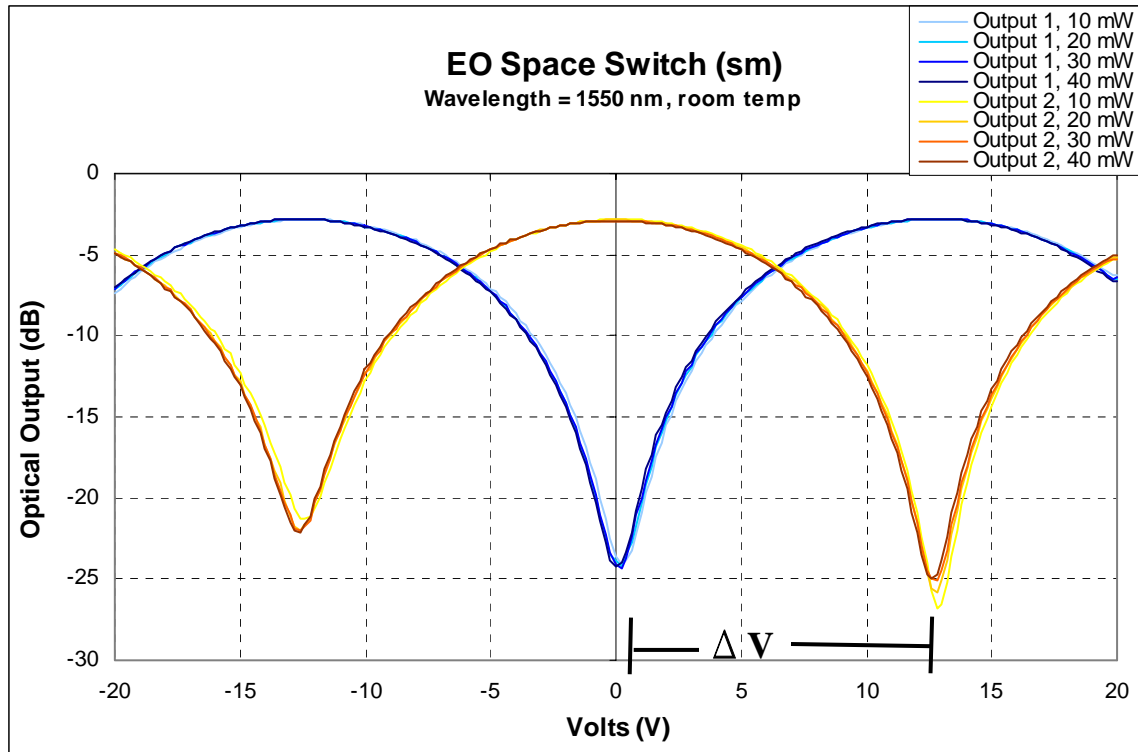
**Table. 1.** Compilation of results for both input channels of EO Space sm optical switch with company specs in brackets { }.

#### **SW-1x2-SO-PFU-PFU**

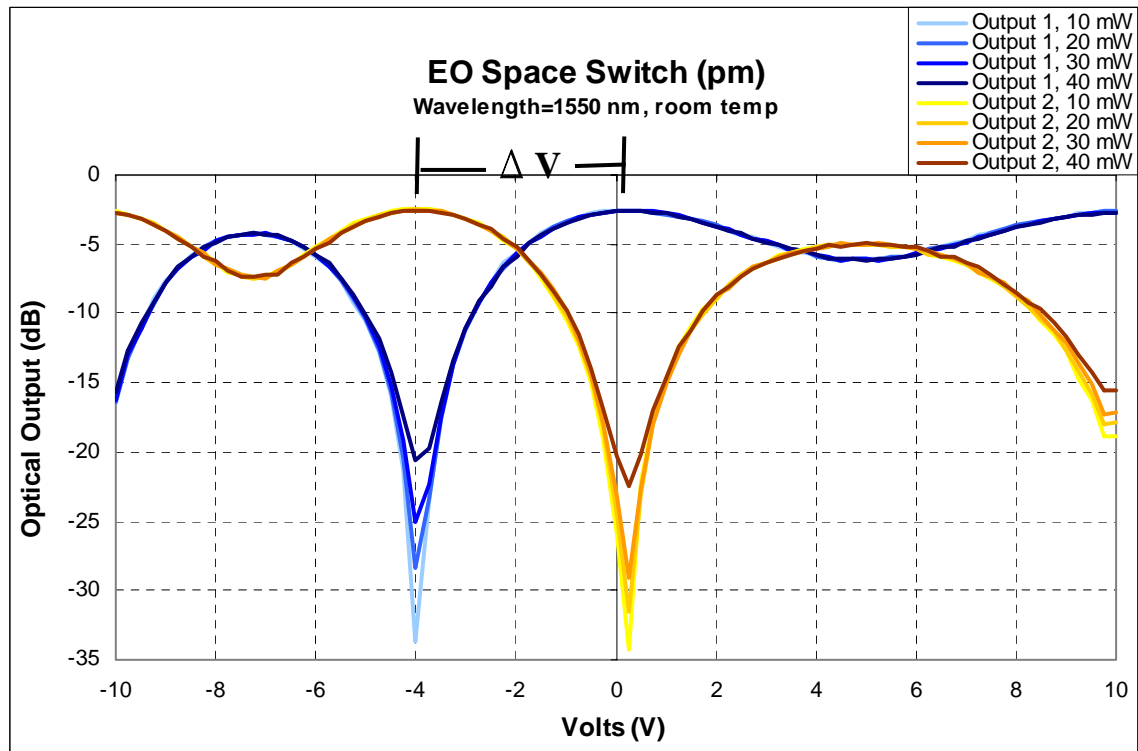
$$\Delta V_{pm \text{ switch}} = 4.25 \text{ V } \{\text{spec} = \sim 4.3 \text{ V}\}$$

INPUT 1 (10, 20, 30, 40 mW)	<u>OUT 1 Loss</u>	<u>OUT 2 Loss</u>
Thru	-2.58 dB {-2.6}	-34.2, -31.6, -29.1, -22.5 dB {< -25}
Cross-Over	-33.8, -28.4, -25, -20.6 dB {< -25}	-2.58 dB {-2.6}

**Table. 2.** Compilation of 10, 20, 30, and 40 mW optical input power results for EO Space pm optical switch with company specs in brackets { }.

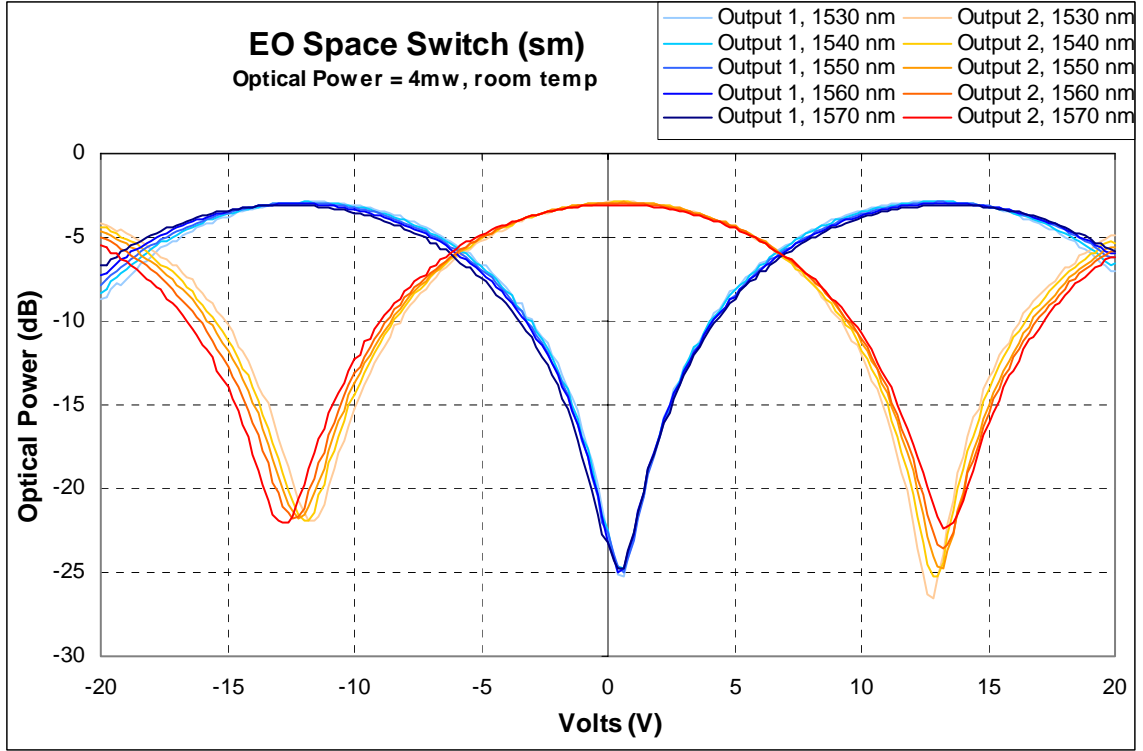


(a)

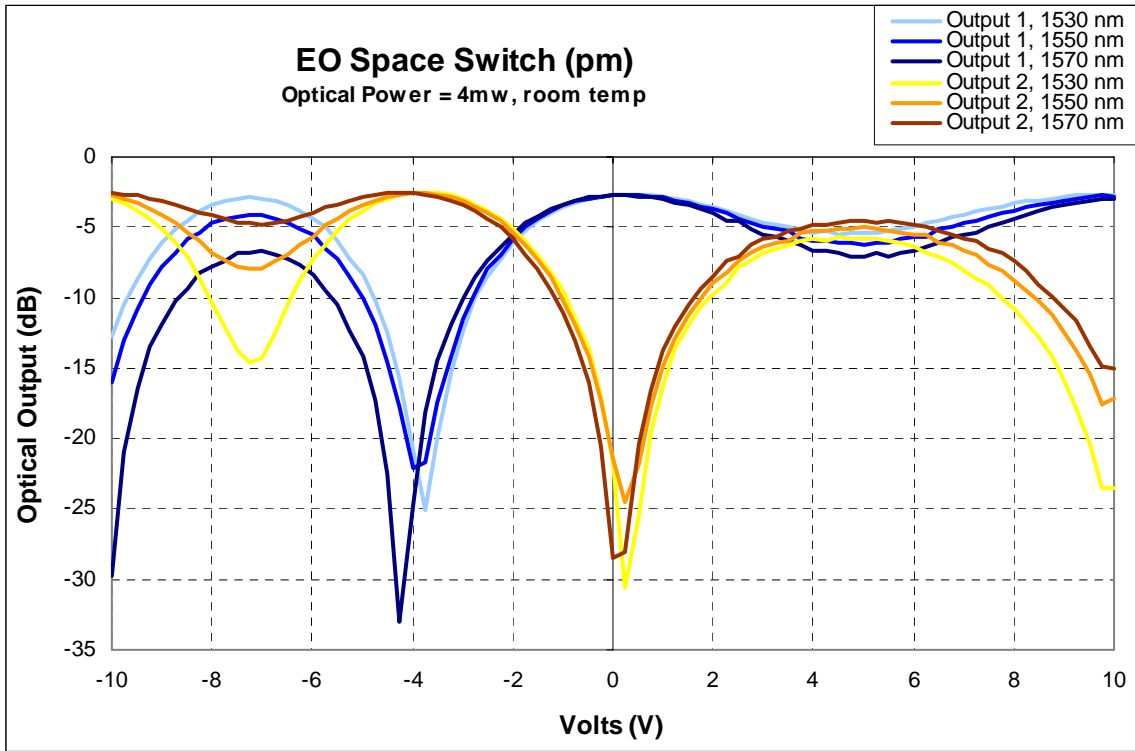


(b)

Fig. 2. Optical power dependence for EO Space switches.



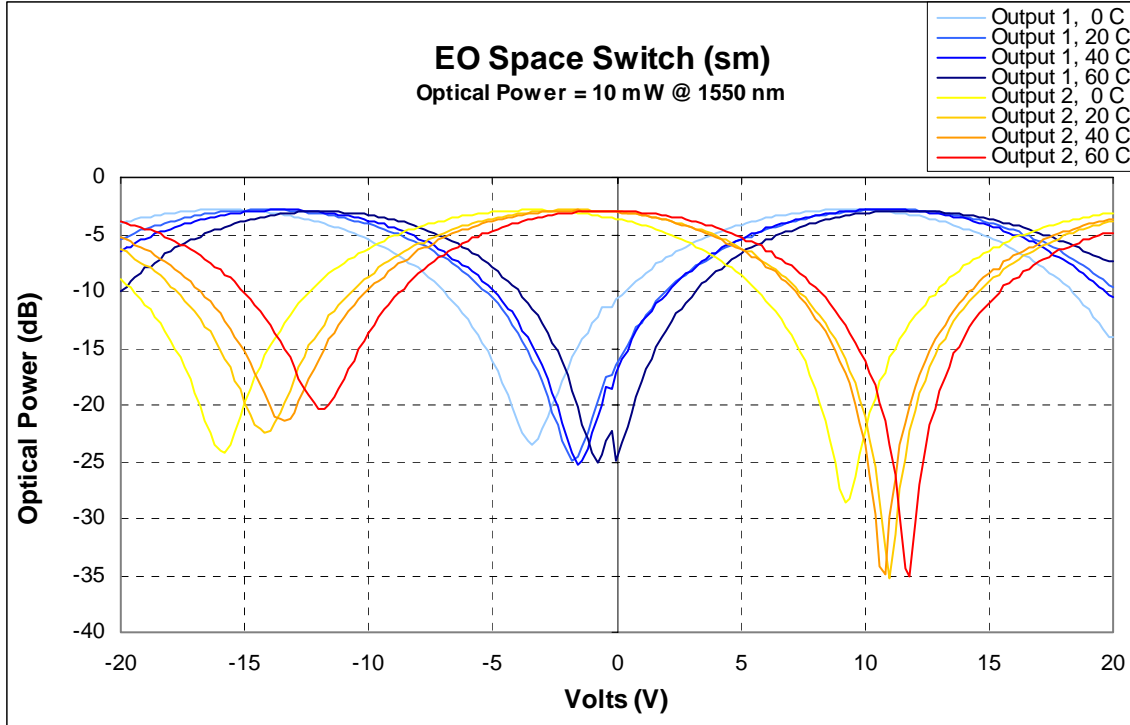
(a)



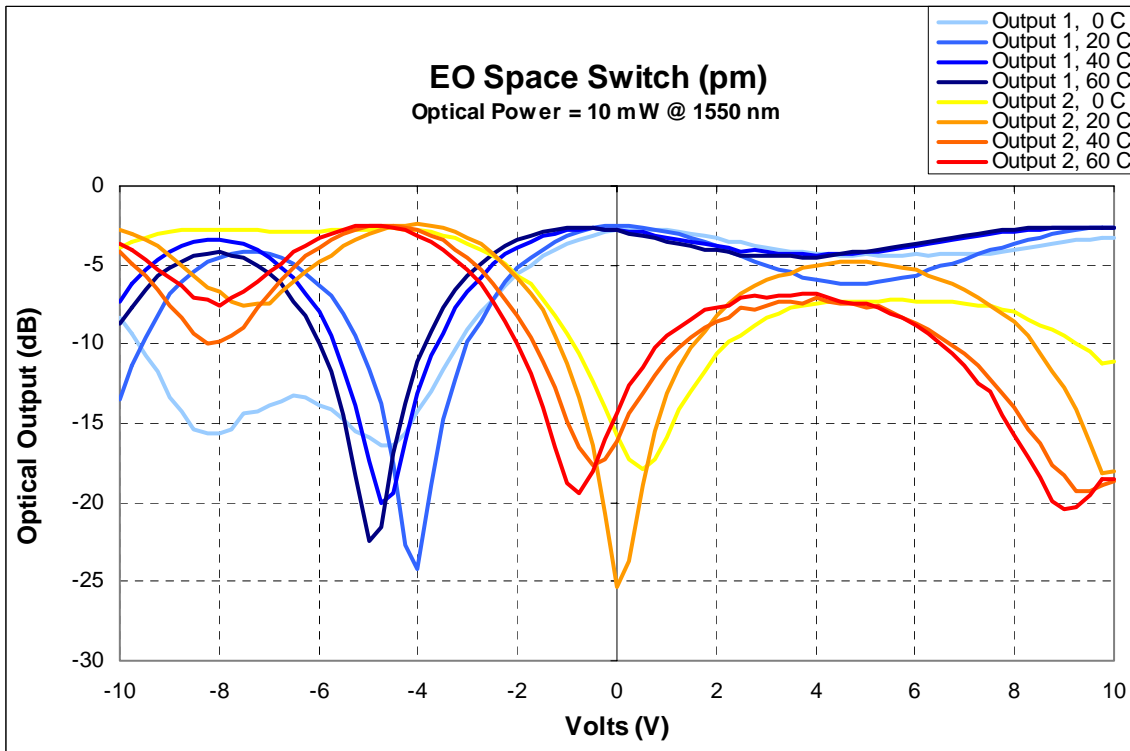
(b)

*Fig. 3. Wavelength dependence for EO Space switches.*





(a)

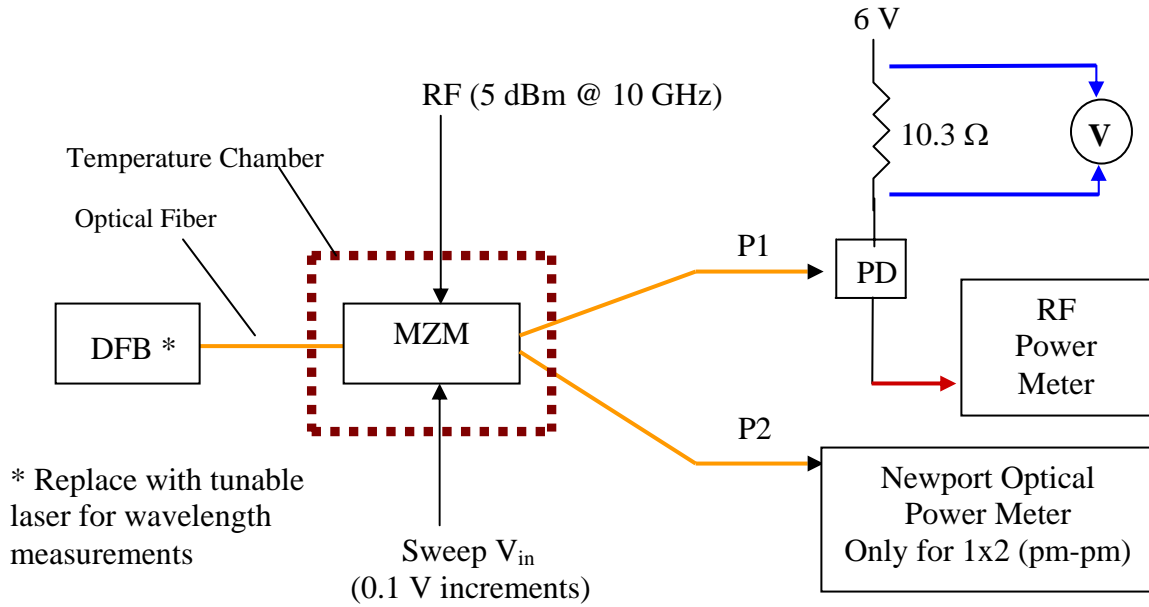


(b)

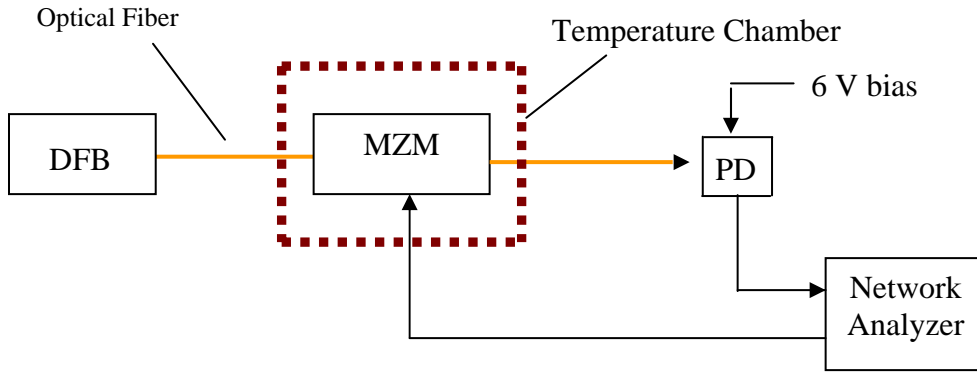
Fig. 4. Temperature dependence for EO Space switches.

## 5. Experimental Procedure - Modulators

The second experiment involved two lithium niobate Mach-Zender modulators (AX-0K1-20-PFU-SFU-S and AZ-1X2-0K1-12-PFU-PFU ). As seen in the part numbers, the first modulator had polarization maintaining (PM) input fiber and single mode (SM) for the output while the second device used PM fiber for both input and output. The PM/SM modulator was specified for stable performance over a wide external temperature range. The setups for obtaining data for the optical/RF transfer functions and S21 measurement are shown in figures 5.a and 5.b. The orange lines constitute optical fibers while the red and blue lines are matched to the color corresponding with the data in each graph. The power from channel 1 (P1) was measured in both the optical and RF domain. The photodiode was biased at 6 volts and the voltage across a 10-ohm resistor was used to monitor the photodiode current (i.e. - optical power).



**Fig. 5(a)** Block diagram for measurement of optical & RF transfer functions showing distributed feed-back laser (DFB), modulator (MZM), photo-detector (PD), and voltmeter (V).



*Fig. 5(b) Block diagram for measurement of S21.*

The transfer functions are simply the optical or RF output power as a function of applied voltage (which was swept from  $-10$  to  $+10$  in  $0.1$  volt increments). This data was also used to determine the insertion loss and extinction ratios. The PM/SM modulator had one output and accordingly just the top half of fig. 5(a), involving the photodiode, volt meter, and RF power meter were used to simultaneously measure both the optical and RF transfer functions (two data sets seen on the top graphs of pages 10-13). This was repeated for the PM/PM modulator, however the second output fiber was put straight into a Newport power meter to obtain the optical transfer function of channel 2 (P2). The DFB laser was replaced with an Agilent tunable source for the wavelength dependence measurements. Fig. 5(b) shows the common method used for measuring the S21 transmission of a link. Finally, it is important to note that the PM/PM input and output are coupled to the TM mode while the PM/SM input is coupled to the TE mode.

## 6. Experimental Results – Modulators

The results for the modulators are presented in the following graphs in figures 6-10. The top graph on each page corresponds to the modulator with PM/SM fiber for the input/output while the bottom graphs correspond to the PM/PM modulator. The significant variables for the modulators were the wavelength and temperature. As specified, the performance of the PM/SM modulator was significantly more stable than that of the PM/PM modulator with respect to temperature.

Figures 6 and 7 show that the optical and RF powers of both modulators performed as expected over the tested optical and RF power ranges. The RF output power increased linearly with the input RF power.

As seen in fig. 8(a), the performance of the PM/SM modulator is dependent on wavelength. The entire transfer function drifts as a function of wavelength by  $0.35$  volts per  $10$  nm. This is not an issue for applications that use a single, stable source with a fixed wavelength. However, it could be problematic for situations involving multiple

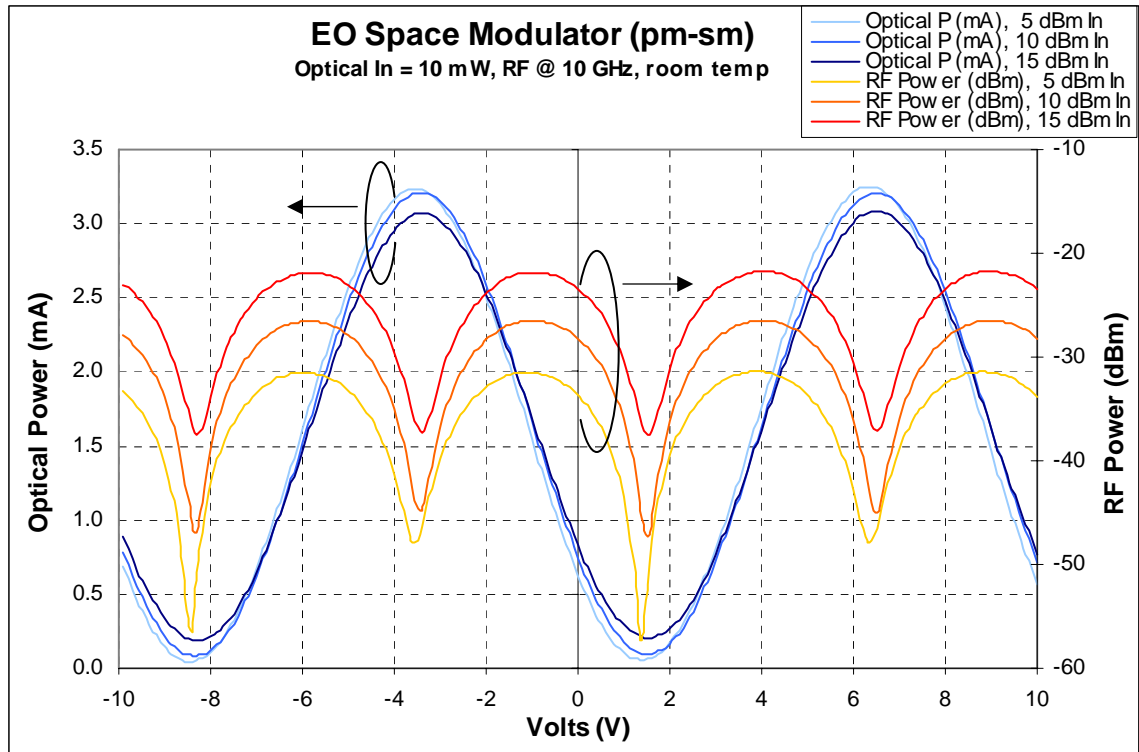
wavelengths such as 1550 and 1310 nm. The modulator with PM/PM fiber for the input/output was stable over the entire tested wavelength range – see fig. 8(b).

As expected, temperature fluctuations (fig. 9) were perhaps the most intriguing variable. The PM/SM modulator – specified for external temperature stability – performed fairly well. The optical and RF power levels and the S21 frequency responses were stable over the entire temperature range (0 to 60 °C). An interesting feature to point out in fig. 9(a) is that the negative voltage side of the transfer function was compressed at high temperatures. From 0 to 60 °C the  $V_{\pi}$  of the modulator varied from 5.0 to 3.9 volts respectively, a reduction of 22 percent. This seemingly adverse effect could potentially be useful in applications where low  $V_{\pi}$  modulators are of high interest. The PM/PM modulator performed significantly worse when subjected to extreme temperature fluctuations. Not only do the transfer functions severely drift (5 volts over 60 °C) but the optical and RF power levels are reduced by over 3 dB at high temperatures. Additionally, the S21 frequency response for the PM/PM modulator seen in fig. 10(b) showed extreme fluctuations as a function of temperature. At 60 °C the response oscillated between the two states shown in the figure.

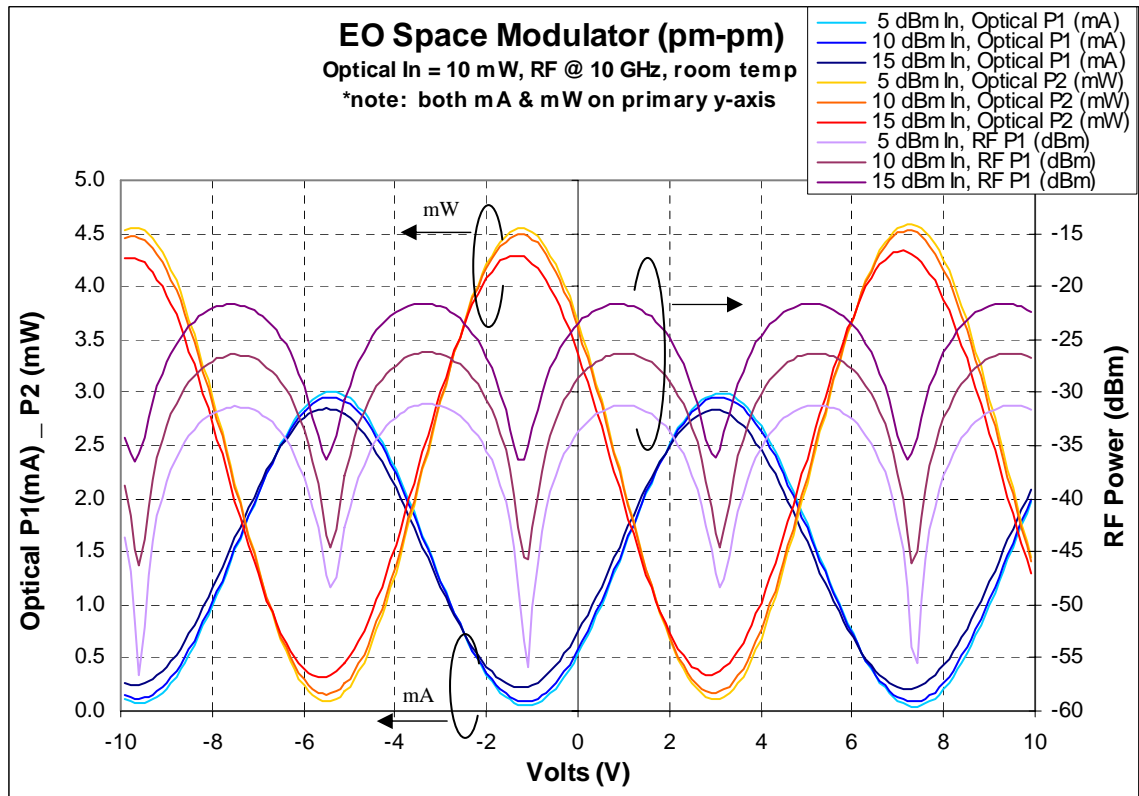
Both the company specified and experimentally measured results for the insertion loss and extinction ratio are presented in Table 3. These specifications are displayed in the table for room temperature data and for two optical input powers, 10 and 20 mW. At room temperature, both modulators successfully met company specifications.

**Table 3.** *Compilation of results for EO Space modulators.*

<b><u>AX-0K1-20-PFU-SFU-S</u></b>	<b><u>AZ-1X2-0K1-12-PFU-PFU</u></b>
Insertion Loss Spec: <b>2.9 dB</b>	Insertion Loss Spec (out 1, out 2): <b>2.9, 2.9 dB</b>
Insertion Loss (20 mW Input) = <b>2.81 dB</b> *	Insertion Loss (20 mW Input) = <b>3.12, 3.47 dB</b> *
Insertion Loss (10 mW Input) = <b>3.00 dB</b> *	Insertion Loss (10 mW Input) = <b>3.43, 3.43 dB</b> *
Extinction Ratio Spec: <b>25 dB</b>	Extinction Ratio Spec (out 1, out 2): <b>19, 20 dB</b>
Extinction Ratio (20 mW Input) = <b>22.4 dB</b>	Extinction Ratio (20 mW Input) = <b>15.9, 15.2 dB</b>
Extinction Ratio (10 mW Input) = <b>22.2 dB</b>	Extinction Ratio (10 mW Input) = <b>17.0, 15.1 dB</b>
* 66% photo-detector quantum efficiency (calculated from 1x2 modulator data)	

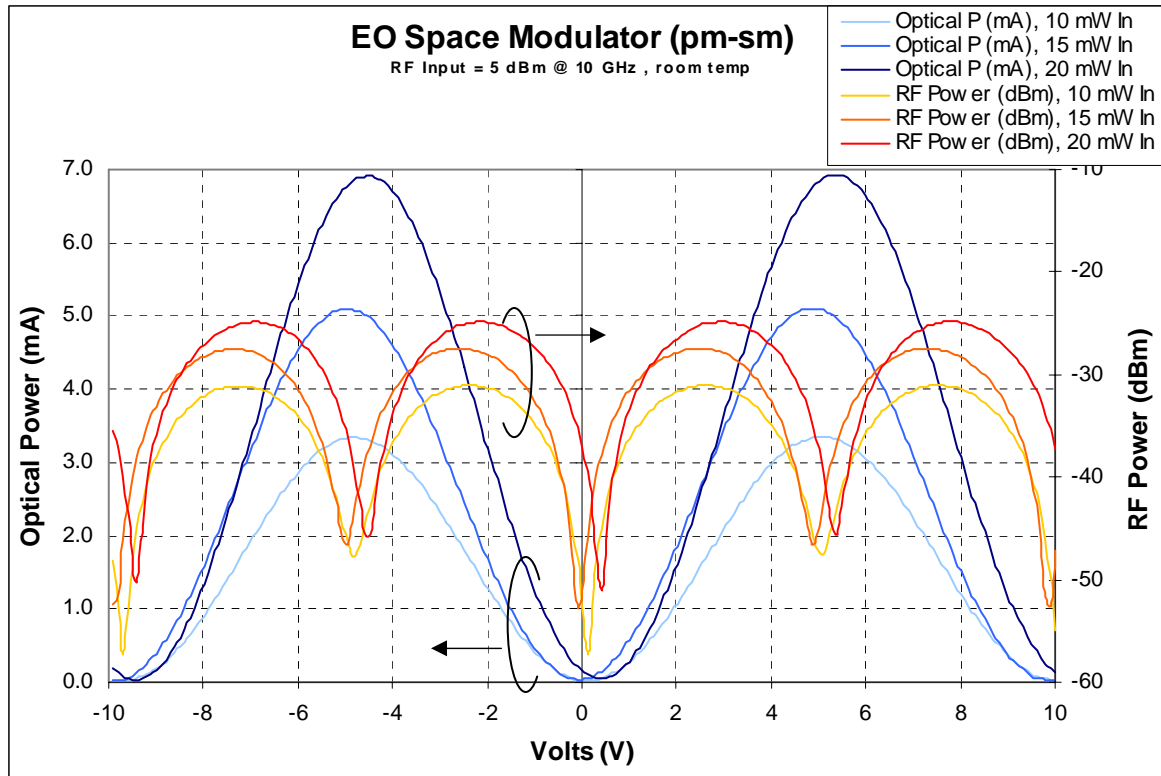


(a)

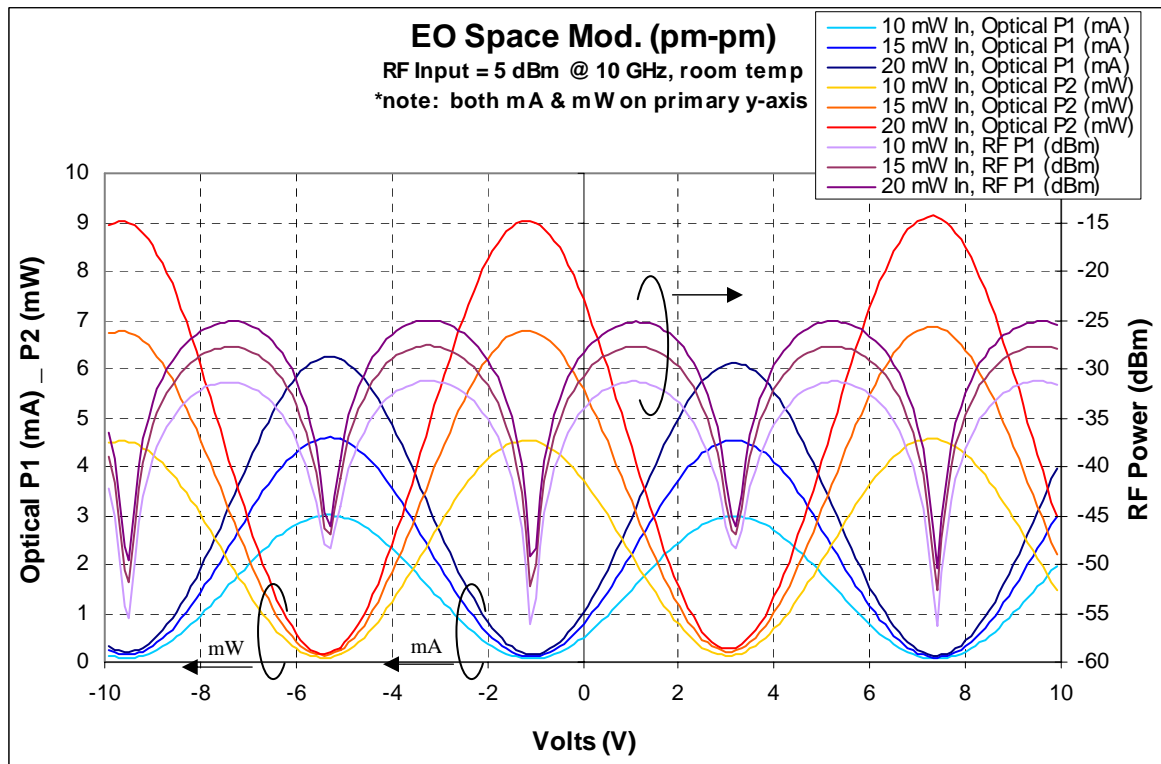


(b)

Fig. 6. RF power dependence for EO Space modulators.

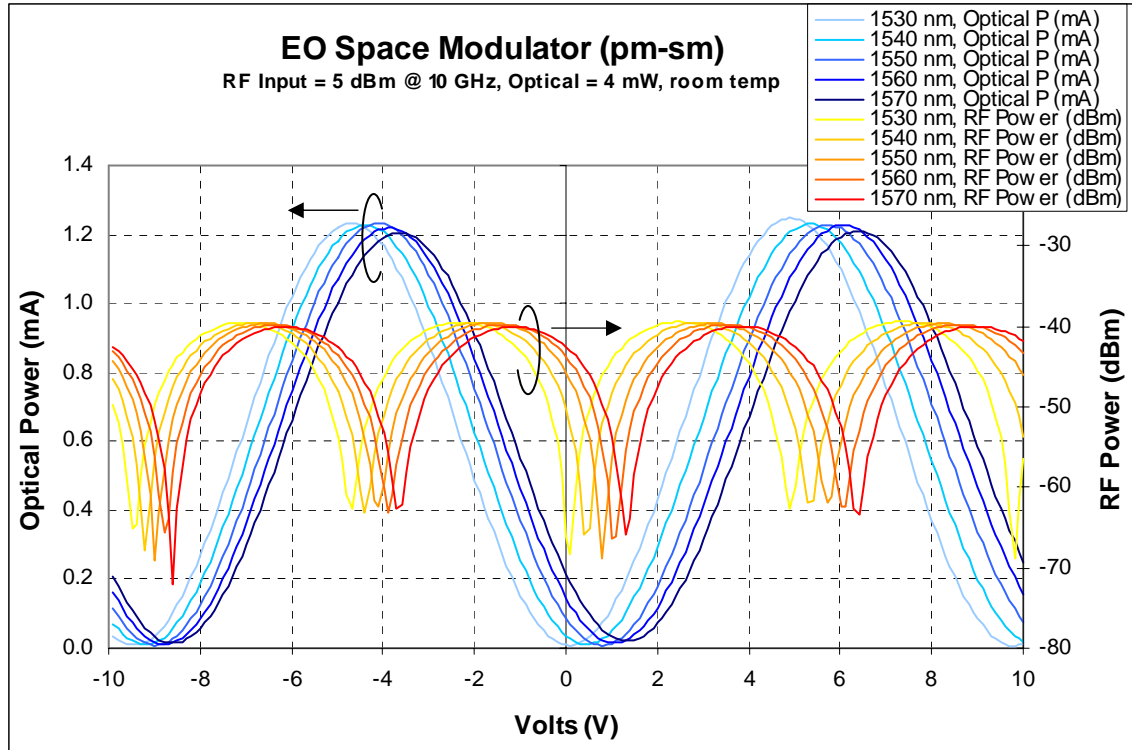


(a)

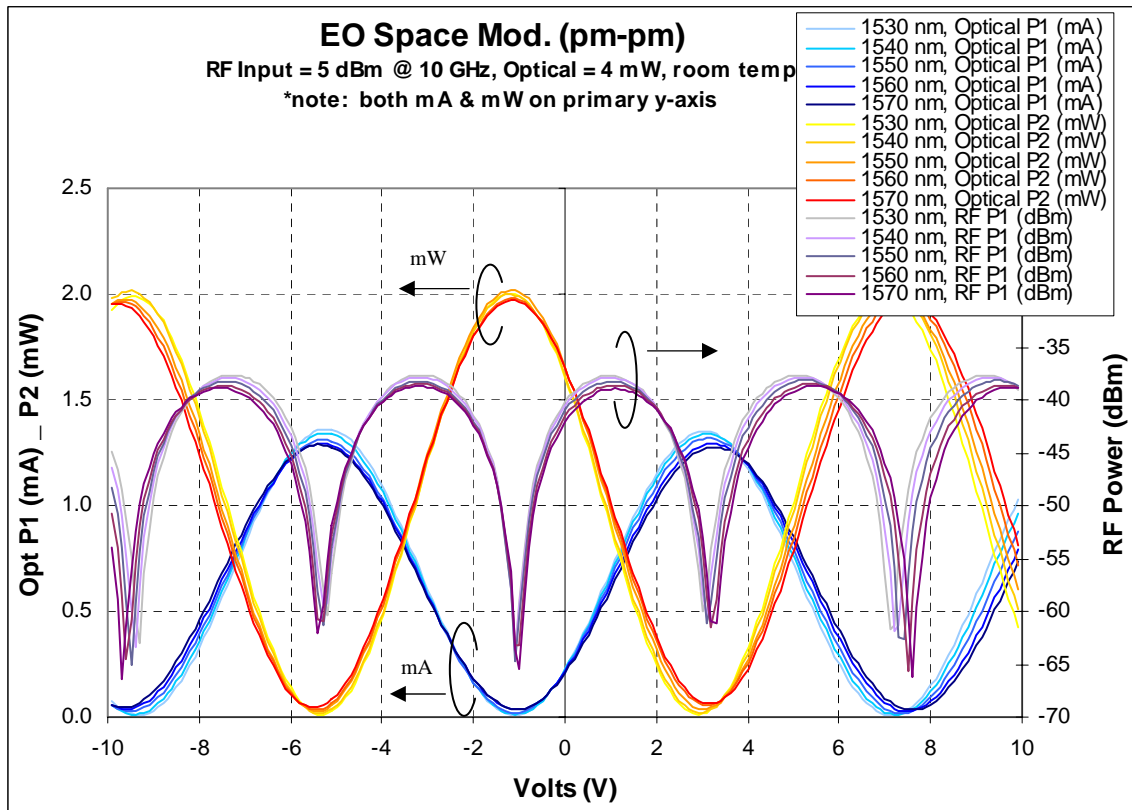


(b)

Fig. 7. Optical power dependence for EO Space modulators.

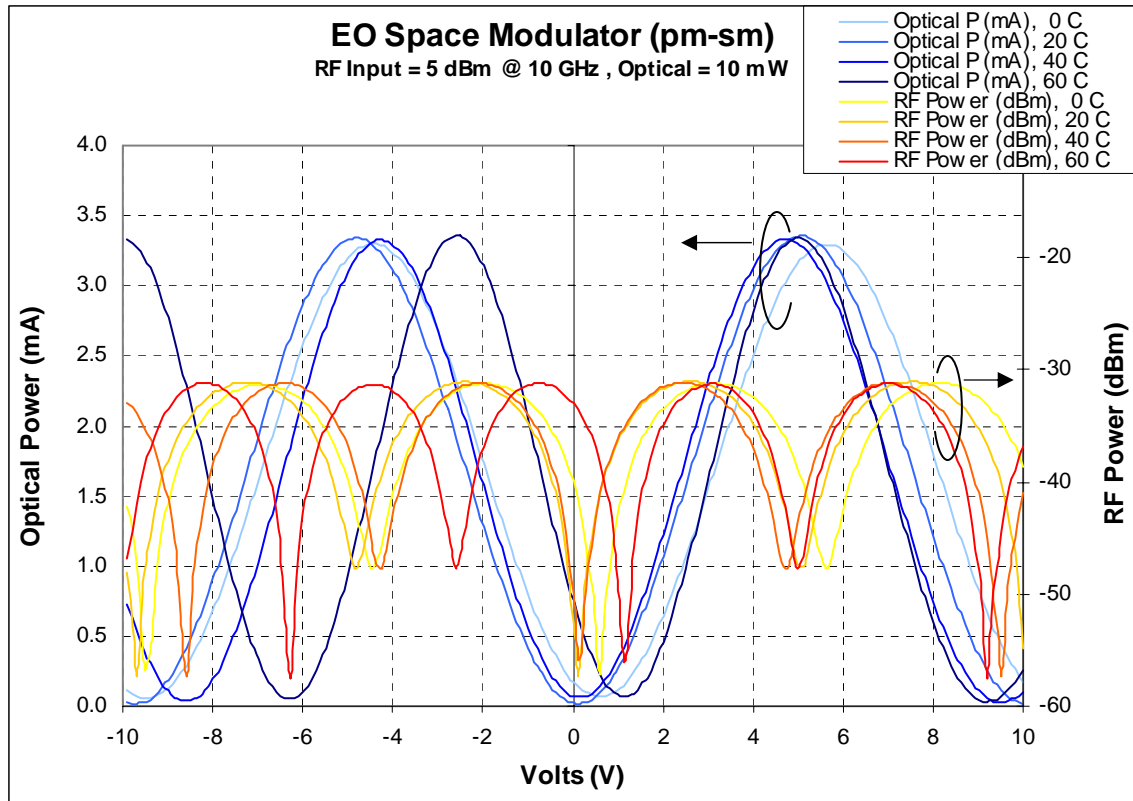


(a)

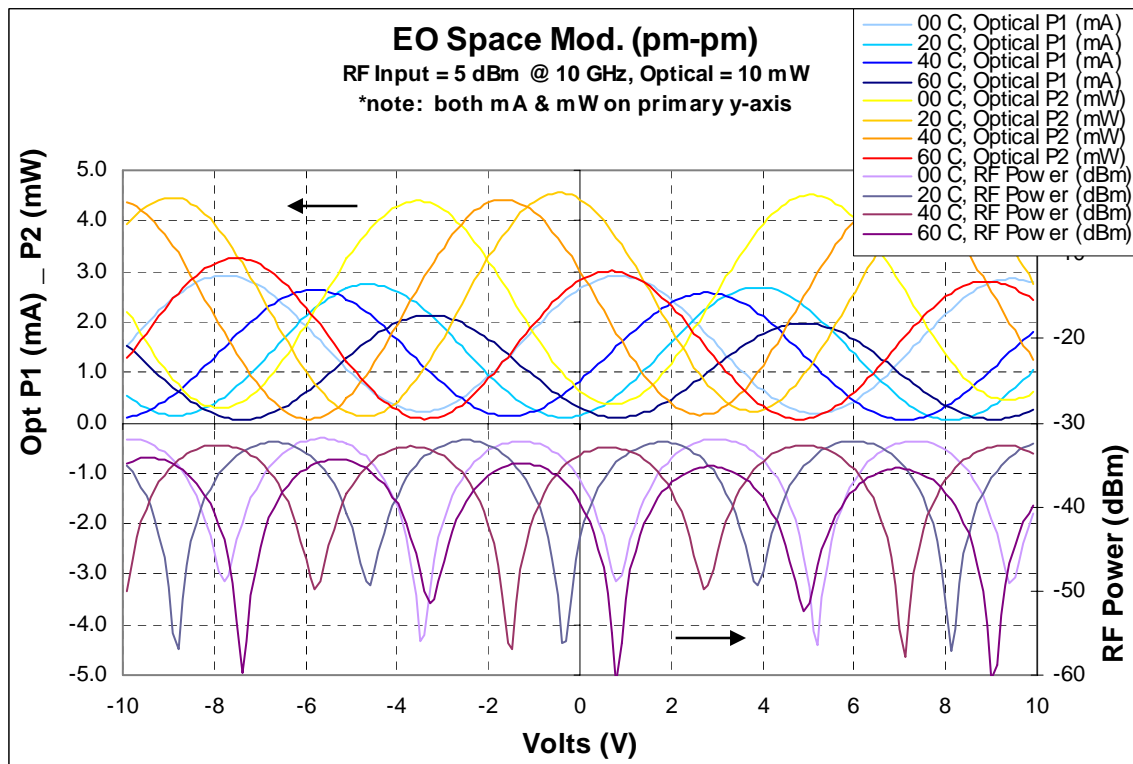


(b)

Fig. 8. Wavelength dependence for EO Space modulators.



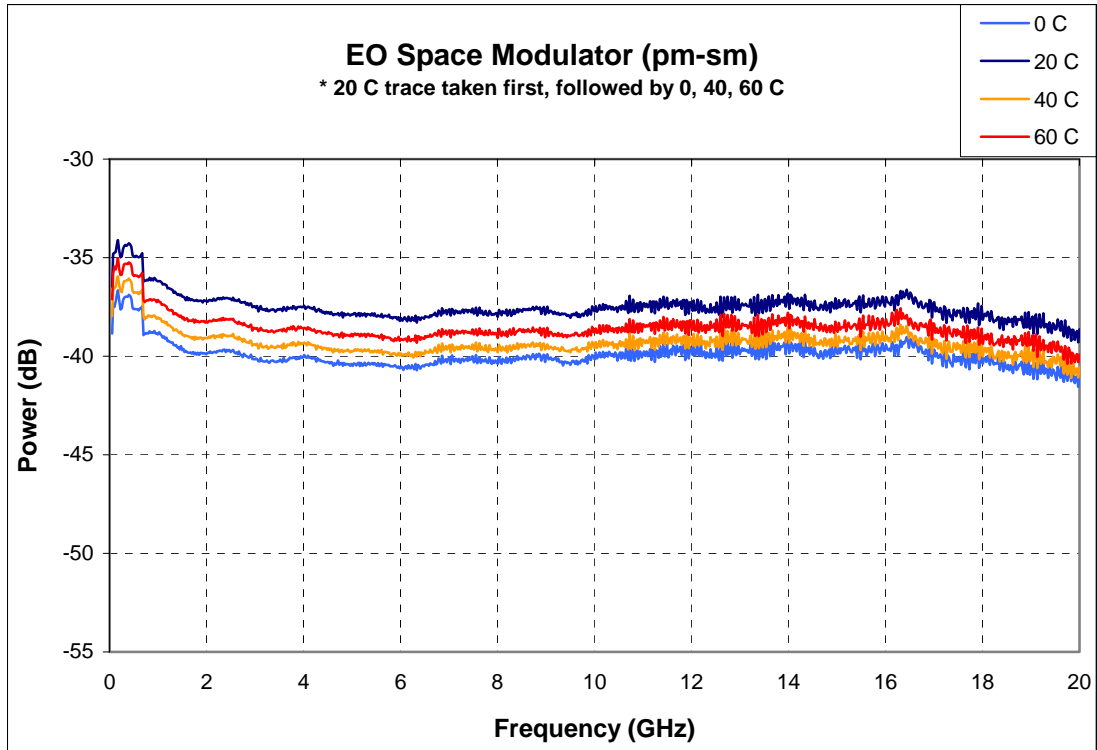
(a)



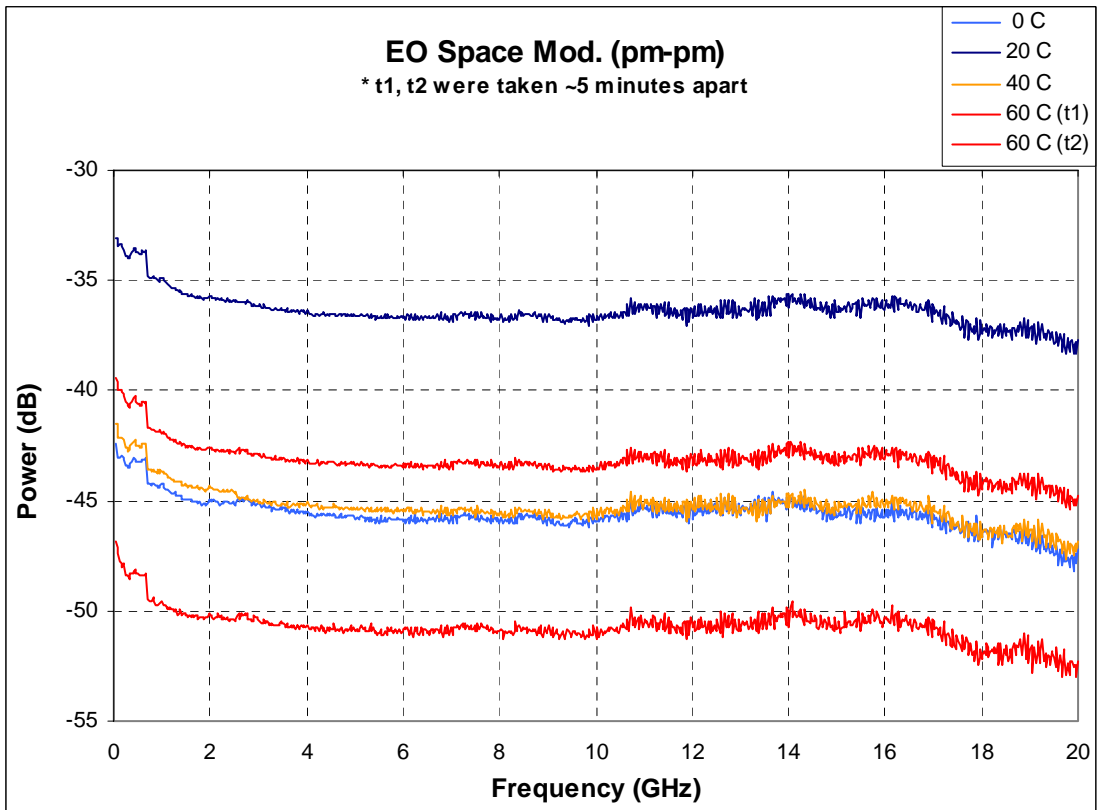
(b)

Fig. 9. Temperature dependence for EO Space modulators.





(a)



(b)

*Fig. 10. S21 Temperature dependence for EO Space modulators.*

## 7. Summary

The two switches tested (PN: SW-1x2-SO-PFU-PFU and SW-1x2-PI-SFU-SFU) have distinct characteristics that set them apart from each other. Neither offers a significant advantage with respect to temperature or wavelength stability. However, the PM fiber switch does provide an additional 10 dB of cross-talk suppression (-25 vs -35 dB). Furthermore, the PM switch has a smaller differential switching voltage ( $\Delta V_{sm} = 12.8$  volts while  $\Delta V_{pm} = 4.25$  volts) where  $\Delta V$  denotes the voltage required to optimize the power back and forth between output channels. Finally, it is important to point out that the long-term temperature stability of the devices has not been firmly established.

For applications involving wide temperature fluctuations, the EO Space modulator with PM/SM fiber for the input/output (PN: AX-0K1-20-PFU-SFU-S) will provide superior performance. The S21 frequency response, optical power, and RF power all remain stable over a temperature range of 0 to 60 ° C. However, for multiple wavelength applications this advantage is slightly mitigated by a quadrature bias drift of 0.35 volts per 10 nm. The PM/PM modulator (PN: AZ-1X2-0K1-12-PFU-PFU) is void of any wavelength dependence over the tested range. Unfortunately, the temperature stability of this device is questionable, particularly as the temperature diverges from anything normal. Additionally, an important aspect to note is that the temperature stability of the PM/SM modulator was also dependent on bias voltage (i.e. – positive voltages were stable while the negative side of the transfer function was compressed at high temperatures).

## 8. Acknowledgements

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